þÿ T e a c h e r i n t e r v e n t i o n s i n s t u d e n t s c o l l a b o r a t i v e technology-rich educational makerspace

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Teacher interventions in students' collaborative work in a technology-rich educational makerspace

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Abstract

This study reports on an investigation of teacher interventions in students' collaborative work in an educational makerspace. We draw on a qualitative analysis of video data on teacher–student interaction derived from 94 students (aged 9–12) and their teachers in a Finnish school. The results show that the teacher interventions were both student- and teacher-initiated. Three leading teacher intervention strategies were identified, namely authoritative, orchestrating and unleashing which emerged in teacher–student interactions dealing with conceptual, procedural, technological, behavioural and motivational issues. The study demonstrates the demands makerspaces pose for teacher–student interaction, and how moving from authoritative to collaborative interaction requires collective efforts and cultural change.

Introduction

Novel technology-rich design and making environments, often referred to as "makerspaces" have aroused recent educational interest (Halverson & Sheridan, 2014; Honey & Kanter, 2013; Kafai, Fields, & Searle, 2014; Keune & Peppler, 2018; Kumpulainen, Kajamaa, & Rajala, 2018; Marsh *et al.*, 2017; Peppler, Halverson, & Kafai, 2016). Makerspaces are an essential materialisation of

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Practitioner Notes

What is already known about this topic

- Makerspaces can enhance students' science, technology, engineering and mathematics learning, creativity, collaboration and other 21st century skills.
- Makerspaces accommodate diverse students and interests.
- Little attention has been paid to the role of the teacher in makerspaces.

What this paper adds

- It generates new knowledge on the nature of teacher intervention in makerspaces.
- It demonstrates the demands and tensions makerspaces impose on teacher–student interaction during teacher intervention.
- It shows that a novel makerspace does not self-evidently change the customary ways of teaching and learning.

Implications for practice and/or policy

- Makerspaces call for flexible ways of working with students and with teams of teachers.
- Teachers need to learn to promote relative expertise and students' responsibility over their learning activity in makerspaces.
- Managing demands and tensions in makerspaces requires continuous collective efforts and cultural change from teachers and students.

the so called "maker movement" that are defined as "sites for creative production in art, science and engineering where people of all ages can blend digital and physical technologies to explore ideas, learn technical skills and create new products" (Sheridan *et al.*, 2014, p. 505). In the context of education, makerspaces typically account for student-driven engagement in hands-on creative activities and projects with a range of technological tools and artefacts (Keune & Peppler, 2018; Peppler *et al.*, 2016).

An emerging body of recent research literature has documented the skills and competencies children might acquire when they participate in makerspaces. For many, making constitutes ways of reaching educationally progressive goals that are not easily realised in more traditional educational practices valuing students' problem-finding, problem solving and collaboration, and where students can develop their abilities to design and produce things utilising various digital and other material resources (Blikstein, 2013; Ramey, 2017; Schrock, 2014; Sheridan *et al.*, 2014; Smith & Smith, 2016). Furthermore, makerspaces are regarded as being well suited to diverse learners, accommodating a diversity of interests and levels of engagement (Johnson & Halverson, 2015). It has been suggested that makerspaces enhance students' agency and persistence in their engagement in learning, contributing to their science, technology, engineering and mathematics (STEM) learning with a design and art-orientation, and provides them with 21st century skills (such as collaboration and digital literacy skills) crucial for working and functioning in contemporary society (Bevan *et al.*, 2016; Peppler *et al.*, 2016).

Despite the educational potential of makerspaces, so far little research attention has been directed to the role of the teacher in facilitating students' learning activities in makerspaces. However, teacher interventions and involvement in student-centred learning activities (such as during collaborative group work situations) has been found to be important in furthering students' productive disciplinary engagement and learning opportunities (see eg, Hofmann & Mercer, 2016).

These findings have also been echoed in recent research on making in museums and in schools that suggest that teacher facilitation is a key issue. For instance, McCubbins (2016) found that students' engagement was linked to their facilitators' knowledge and support.

To understand the educational potential of makerspaces, it is crucial for further research attention to be directed to the role of the teacher. In our research, we are particularly interested in the nature of teacher interventions and strategies, and how these support student-driven learning activities and peer collaboration. In this study, we investigate teacher interventions in a student-driven, technology-rich educational makerspace called the FUSE Studio. We ask (1) When do teachers intervene in students' learning activity in the educational makerspace? (2) Which intervention strategies do the teachers use?

Earlier studies on teacher interventions

The existing research on teacher intervention has consistently reported that it is crucial for students' collaborative work and learning (eg, Chiu, 2004; Dawson, 2010; Dekker & Elshout-Mohr, 2004; Ding, Li, Piccolo, & Kulm, 2007; Johnson & Johnson, 2002; Yackel, Cobb, & Wood, 1991). A student group may be driven off-task if there is a lack of teacher intervention (Chiu, 2004). Teacher intervention has been identified as enhancing students' thinking skills and students' ability to complete tasks collaboratively (eg, Ding *et al.*, 2007). Previous research has also illuminated the situatedness of teacher intervention, proposing that qualitatively different intervention strategies are needed for different students, tasks and situations. The frequency and length of teacher intervention has also been reported to influence the quality of the interventions which are found to be dependent on the group situation and the needs of the group. However, some research evidence has pointed to the negative effects of prolonged teacher intervention on student learning (Ding *et al.*, 2007).

Earlier research also underscores the importance of teacher intervention for enhancing the development of students' conceptual understanding in computer-supported learning settings (Dawson, 2010; Greiffenhagen, 2012; Hakkarainen, Lipponen, & Järvelä, 2002; Mäkitalo-Siegl, Kohnle, & Fischer, 2011; Strømme & Furberg, 2015; Webb *et al.*, 2009). Moreover, studies on computer-supported collaborative learning highlight how the introduction of digital resources and tools embedded in the learning environment add to the complexity of teacher–student interaction (Strømme & Furberg, 2015). For example, a recent study by Strømme and Furberg (2015) analysed teachers' concerns emerging in student–teacher interaction during computer-supported learning in an upper secondary science class. Based on their study, the authors stressed the importance of transferring of the scientific expert position from the teacher to the participating students. Further, the study points out the complexity of teacher interventions at the intersection of students and their needs, digital and other tools in use, and the instructional design (see also Furberg & Ludvigsen, 2008; Säljö, 2010).

Some sociocultural studies have explored teacher interventions as part of dialogic processes of teaching and learning (Littleton & Howe, 2010; Mercer, Dawes, Wegerif, & Sams, 2004; Mercer & Howe, 2012; Stahl, 2006). For example, Hofmann and Mercer (2016) investigated teacher interventions in small group work in secondary mathematics and science classrooms from this perspective. The study revealed three intervention strategies the teachers used in their interactions with students, namely (1) authoritative, (2) initiating and (3) continuing interactive intervention strategies. Altogether, the study highlights the reason and motivation in teacher interventions, stating that "changing teachers' current classroom practice needs to be embedded in an understanding of what motivates that practice, what purposes it serves" (Hofmann & Mercer, 2016, p. 413).

By focusing on educational makerspaces that underscore student-centred creative design principles, our study departs from more "prototypical" studies of teacher interventions that have focused on "fixed" groups of students working on more traditional educational tasks in "regular" classrooms (eg, Chiu, 2004; Ding *et al.*, 2007; Johnson & Johnson, 2002). Instead, the aim of our study is to further research on teacher interventions in students' collaborative work in a novel context of a technology-rich educational makerspace. Moreover, in our study we investigate teacher interventions that are initiated by both the teachers and students, adding to the previous studies that have mostly focused on teacher-initiated interventions.

Study

Research setting

This study is situated in a Finnish city-run comprehensive school catering for 535 students and staffed by 28 teachers. The school had recently introduced a FUSE Studio makerspace into their programme in response to the learning requirements of the Finnish National Core Curriculum for Basic Education (OPH, 2014), emphasising student-centred modes of teaching and learning, design and creativity, as well as digital literacy.

The FUSE Studio makerspace (www.fusestudio.net) is a special kind of technology-rich educational programme that offers students a choice of about 30 integrated STEAM making and design challenge sequences that "level-up" in difficulty like video games (see also Salen & Zimmerman, 2005). It is designed to promote students' interest-driven and collaborative learning in STEAM subjects by engaging students in different challenges, such as the *Solar Roller*, *Electric Apparel* (60 minutes) and *Jewellery Designer*, that include robotics, game design, electronics and graphic design (Stevens & Jona, 2017; Stevens *et al.*, 2016). The challenges are accompanied by various tools, such as computers, 3D printers and other materials (eg, foam rubber, a marble, tape and scissors, etc).

The pedagogical principles of the FUSE Studio makerspace underscore relative expertise between students and teachers in which all participants can equally identify each other as learning resources (Champion, Penney, & Stevens, 2016; Penney, Jona, & Stevens, 2016; Stevens *et al.*, 2016). There is no formal grading or assessment by teachers in the FUSE studio. Instead, using photos, video or other digital artefacts, students can document their completion of a challenge which unlocks the next challenge in a sequence. The FUSE studio thus breaks away from the assumption that makerspaces cannot exist in schools with disciplinary standards for curriculums and assessments (Sheridan *et al.*, 2014).

Data collection

The data for this study were derived from 85 hours of video recordings of 9–12-year-old students' ($N = 94$) making and design activities collected intermittently over a period of one semester in the FUSE Studio makerspace located in the everyday premises of the school. As an elective course, the FUSE Studio was optional, and the participating groups were formed by students from several classes. There were 32 students (22 boys and 10 girls) in the fourth grade group, 30 students (19 boys and 11 girls) in the fifth grade group and 32 students (19 boys and 13 girls) in the sixth grade group. The groups were supported by 2–4 teachers and teaching assistants. At the beginning of the semester, each group had one 45-minute FUSE session a week. Later in the semester, each session was extended to 60 minutes.

The school had four male (given here the pseudonyms: John, Greg, Bill and Sam) and one female teacher (Beth) who facilitated the FUSE Studio makerspace sessions. Greg is a secondary school crafts teacher (hard materials) who is in charge of the FUSE team of teachers. John, Beth, Bill and Sam are primary school teachers, Bill and Sam also teach crafts (hard materials).

Data analysis

The video data of teacher–student interaction in the FUSE Studio makerspace were transcribed verbatim. In our data analysis, we used an iterative approach, which is an inductive form of analysis that "encourages reflection upon the active interests, current literature, granted priorities and various theories the researcher brings to the data" (Srivastava & Hopwood, 2009, p. 77). On this basis, the data were first approached by viewing the video corpus as a whole and then focusing on selected events in which the teacher(s) noticed the students' need for support and/or when the student(s) initiated contact with the teacher to help them (Derry *et al.*, 2010; Erickson, 2006). Our analysis also applied the techniques provided by Jordan and Henderson (1995) to depict the nature and context of teacher intervention episodes, the unit of our analysis. A teacher intervention episode was considered to begin when a teacher joined in the students' work either on their own or because of the students' request. We considered the interaction episode to have ended when the teacher or students withdrew from the interaction situation. In our analysis, we also distinguished between whether teacher interventions were initiated by the teacher or the students. On this basis, we depicted 55 intervention episodes in which teacher intervention was initiated by either the teacher or the students.

To respond to our first research question; *When do teachers intervene in students' learning activity in the educational makerspace?* our analysis revealed five main thematic categories in relation to the interactional context of teacher intervention episodes; (1) conceptual, (2) procedural, (3) technology, (4) behavioural and (5) student motivation related teacher interventions (see Table 1). To respond to our second research question, *Which intervention strategies do the teachers use?* our analysis continued by further analysing the 55 intervention episodes and identifying episodes that included indications of specific intervention strategies applied by the teachers. We identified

Table 1: Examples of teacher intervention episodes

The teacher intervention episodes	*Description*	*Example*
1. Conceptual	Teacher intervention episodes connected to the FUSE studio's maker challenges, including students' lack of content knowledge and difficulties in completing a challenge, eg, understanding the instructions	Two girls are designing models during the maker challenge named the *Keychain Customizer*. They do not understand the instructions and the teacher assists them
2. Procedural	Teacher interventions that focus on where to locate and/or how to use varied materials and tools needed for the maker activities (eg, foam rubber, a marble, tape and scissors)	A student needs felt to proceed with a challenge and asks the teacher for help. The student and the teacher go searching for the felt together
3. Technological	Teacher interventions that address technical issues or technical difficulties with the technological equipment and/or hardware	The speedometer is not working, and the students ask the teacher for help
4. Behavioural	Teacher interventions when the students disrupt each other or do not follow joint rules	Students are playing on their smartphones and the teacher tries to refocus them on the maker challenge
5. Motivational	Teacher interventions in relation to problems with the students' motivation towards working on the maker challenges	Two students are reluctant to start to work on a maker challenge and the teacher attempts to motivate them to start working

three main intervention strategies that the teachers used. Namely, (1) authoritative, (2) orchestrating and (3) unleashing. It should be noted that our interest in this study is in illuminating the teachers' use of these intervention strategies across the FUSE Studio sessions, and not to report or evaluate the interactional behaviour of the individual teachers.

Findings

Teacher intervention episodes

We next discuss our findings in relation to the interactional situations in which teacher interventions occurred in our study. These categories are described in Table 1 and present an example of each intervention category: (1) *Conceptual* interventions were directly connected to the maker challenges of the FUSE Studio and difficulties in proceeding with or completing the challenge. These difficulties were typically associated with the instructions or lack of content knowledge that was required for pursuing the challenge; (2) *Procedural* interventions were connected to requests and problems encountered by the students in locating and/or using different materials and tools needed for the maker activities (eg, foam rubber, a marble, tape and scissors); (3) *Technology-related* interventions were connected to the difficulties and malfunctioning of the equipment, hardware and technical infrastructure of the FUSE Studio makerspace. If a student did not know how to use a specific piece of software, this was not categorised as a technical difficulty but as conceptual intervention since learning how to use software was one of the learning objectives of the FUSE Studio makerspace; (4) *Behavioural* interventions were connected to situations in which the students were disrupting others' work or not following joint rules. These situations could be initiated by either the teacher or the students. A student-initiated behavioural intervention typically resulted in students asking for the teacher's help to act on another student's misbehaviour; (5) *Motivation*-related interventions were connected to situations in which the students were unwilling to focus on their work in the FUSE Studio makerspace. Motivation-related interventions were separated from behavioural interventions since they did not show the students' disturbing each other or breaking any school rules.

Figure 1 presents the distribution of teacher intervention episodes. Most of the intervention episodes focused on issues related to *conceptual* issues in relation to working on the maker challenges, (21 interventions, 38%). The second largest category related to behavioural issues (12 interventions, 22%), when the students misbehaved during the session or deviated from the joint rules and instructions. This was followed closely by *procedural* related teacher intervention episodes (11

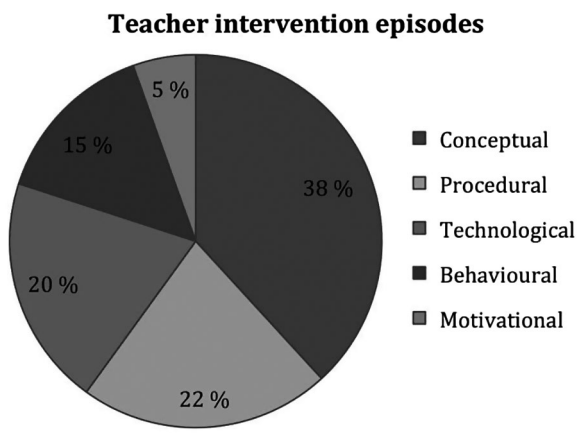

Figure 1: The distribution of teacher intervention episodes

interventions, 20%). The fourth largest category was technology-related teacher intervention episodes (8 interventions, 15%). Finally, the least frequent intervention category dealt with the students' motivation (3 interventions, 5%).

Figure 2 presents the number of teacher intervention episodes initiated by the teachers and the students. While conceptual- (76%), procedural- (90%) and technology- (75%) related interventions were mostly student initiated, most of behavioural (92%) and all motivation-related (100%) interventions were teacher initiated.

Teacher intervention strategies

We identified three dominant strategies that characterised the teacher–student interaction during teacher interventions, namely (1) *authoritative*, (2) *orchestrating* and (3) *unleashing*.

Authoritative intervention strategy

Authoritative refers to an intervention strategy in which the teacher took charge of the work, typically dominating and/or controlling the students' learning activity. This often meant that the teacher would not ask questions of the students but would rather instruct them step-by-step towards resolution (see also Hofmann & Mercer, 2016). Further, the teachers would not confirm whether the students understood the reason behind each solution or step, or if they would have been able to take some responsibility over the problem-solving, thus encouraging scaffolded support and joint reasoning. Sometimes the teacher was solving the FUSE maker challenge on the student's behalf. The teachers' use of the authoritative intervention strategy was quite common in intervention episodes that dealt with the students' behaviour or motivation. However, it was also visible in teacher–student interactions that concentrated on procedural, conceptual and technological issues as demonstrated in Example 1.

The following teacher intervention episode (Example 1) focuses on conceptual and procedural aspects and was initiated by a student, Mary, who was working side-by-side with another student Lisa on their individual design challenges: The students are both using SketchUp software on their laptops to design and make their own *Jewelry Designer* challenge. Mary asks for help from the teacher Beth about using SketchUp but as the other teacher Greg is known to be more knowledgeable in the use of the software, he is called upon. First, Greg asks Mary to get a separate mouse (line 3) while he sits down at her laptop. Throughout the intervention, Greg operates the software

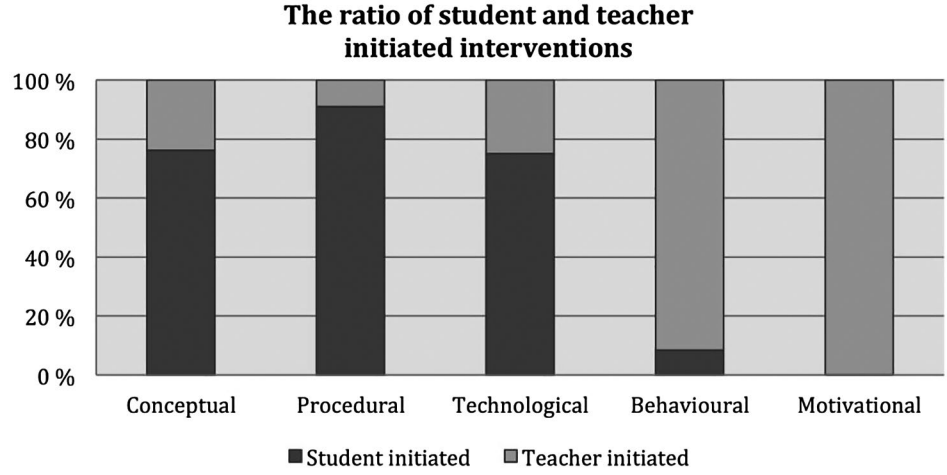

Figure 2: The ratio of student- and teacher-initiated interventions according to the interactional context

on the student's behalf thus not letting her try the commands herself. When Mary tries to make a suggestion of a solution, the teacher does not agree but explains his own solution.

Example 1

3. Teacher Greg: "Did you get that mouse? Remember it is easier to draw with it? [Mary goes to get the mouse and the teacher sits down at her laptop.]
4. Student 2/Lisa: "I did this stripy, zebra thing. What does it do? Where does it go?"
5. Teacher Beth: "Yeah I tried that, but it didn't…"
6. Student 1/Mary: "Well it went like this that there is a line in the middle".
7. Teacher Beth: "You can still undo it".
8. Teacher Greg: "Everything can be undone. So, what is this, in what way is it slanted?"
9. Student 1/Mary: "Well it has gone like this [does a horizontal line with her hand] because…"
10. Teacher Greg: "Was it a triangle to begin with?"
11. Student 1/Mary: "Yeah".

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17. Student 2/Lisa: "Does it work now?"
18. Teacher Greg: "I think it's still… Oh yeah, it looks pretty good now".
19. Student 1/Mary: "Except those two are a little slanted".
20. Teacher Greg: "Well then it's like that. But yeah. See this is just that you have to remember to look at it from different directions. Because from one perspective it might look good like here but when you look at it from the side, it is a bit slanted. And well".
21. Teacher Beth: "Is it actually now kinda…?"
22. Teacher Greg: "Now it's levelled. It's okay like this but it's not like, not like this [shows with hands] but it's more like you noticed that the square is not quite [even] when you look here".
23. Student 1/Mary: "The corners are not the same…"
24. Student 2/Lisa: "How do you get this…"
25. Teacher Beth: "Right that's the one that you can spin it with…"

In Example 1, Greg is practically working independently while the others try to see and comprehend what he is doing. Even though Greg tries to explain what he is doing aloud (lines 20 and 22), he does not stop to see whether others are following and understanding his activity. The other teacher Beth tries to offer comments and ideas at the beginning (lines 5, 7, 21 and 25) but gives up at some point and leaves to help other students.

The other student, Lisa, keeps listening to the conversation and occasionally stopping her own work to look at Mary's screen. Lisa tries to ask questions about her own work (lines 4 and 24), but is only acknowledged when she comments on Mary's design (line 17). Overall, the teacher Greg does not encourage interaction between the students. Instead, he answers and guides each of the students separately, even though the girls have been working side-by-side since the beginning of the challenge.

Orchestrating intervention strategy

We depicted another intervention strategy, orchestrating, through which the teachers purposefully took account of students' contributions to the interaction by listening to the students and inviting them to reason and explain. Typically, here, the teachers also tried to balance and/or to "glue together" the diverse needs and ideas presented in the interaction situation between the students and the teacher (see also Kovalainen, Kumpulainen, & Vasama, 2001; Strømme & Furberg, 2015).

We could identify features of the teachers' orchestration strategies in many intervention episodes focusing on conceptual, procedural and technological issues as demonstrated in Example 2. The

orchestrating intervention strategy was less common in interaction episodes that dealt with the students' behaviour or motivation to engage with the maker activities. In Example 2, the teacher intervention led to subsequent peer collaboration and encouraged interactions between the students themselves. In this episode, the teacher John is encouraging the students to help each other and to work collaboratively. Simultaneously, he begins to "glue" the students' experiences and knowledge on the topic together.

Example 2

1. Student 1/Tara: "I would like to turn this so I can get to the other side".
2. Student 2/Hanna: "Me too, because I don't even know how to get there".
3. Teacher John: "Well wait, let's see who is furthest along in Dream Home. Eric and Ian, have you rotated the angles there so you can get to the other side of the house?"
4. Student 3/Rick: "I have!"
5. Teacher Greg: "Hold down the mouse's button and then spin".
6. Teacher John: "Okay, Rick can come and instruct".
7. Student 3/Rick: "What?" [Comes over to the girls.]
8. Student 2/Hanna: "How on earth do you turn this?"
9. Teacher John: "Hold down the mouse and…"
10. Student 3/Rick: "What did you want to do?"
11. Student 1/Tara: "Rotate the angle".
12. Student 3/Rick: "Take that and then…" [Tara rotates.]
13. Teacher John: "Which one was it Rick? Why don't you show me too".
14. Student 3/Rick: "This tool".
15. Teacher John: "Oh!"

In Example 2, the teacher John uses an orchestration strategy in his intervention into the students' work initiated by two students Tara and Hanna. The students do not know how to use the software to design and make a Dream Home. While using an orchestrating intervention strategy, the teacher encourages the students to share their knowledge and experiences in solving the challenge. Interestingly, the other teacher (Greg) who is present in the situation, tries to instruct the students by giving direct instructions (line 5) before the student Rick joins the interaction. By asking the students to help one another (lines 3, 6 and 19) and the teachers themselves (line 13), the teacher John is recognising the students as knowledgeable and accountable partners, identifying them as learning resources in furthering the work. In his orchestration strategy, he creates opportunities for the students' relational engagement and expertise (see also Edwards, 2017; Edwards & D'Arcy, 2004). This episode also makes clear that the teachers have different and at times slightly conflicting strategies in responding to the students' needs in their interventions.

Unleashing intervention strategy

We also found teacher intervention strategies that attempted to further the students' creative work, which we call unleashing. In these interaction episodes, the teachers explored the students' existing knowledge, encouraged them to compare and to test their own ideas, and to identify conceptual or material resources for their work and reasoning (see also Hofmann & Mercer, 2016). Further, in some cases the teacher allowed the students to deviate from the rules and instructions. This usually led to the creation of something surprising, such as, extending the maker challenge. Overall, these interventions were rare in the data, but since such creative interactions are at the core of the makerspaces, we regard them as being important enough to document in the data.

In Example 3, Anton (student 1) wants to start working on *Jewellery Designer* (Level 1). He asks the teacher for help. Mike (student 2) is standing behind Anton and wants to know what he is going to do. Anton tells him that he's going to design a wristband and print it out with the 3D printer when it arrives. The instructions for the challenge are in English. The teacher (Beth) translates them for the student. The instructions explain that at the first level of the challenge, the student needs to design a simple earring model. Anton doesn't want to design earrings and asks the teacher if he can design something else. The teacher replies to him that at level one he is supposed to design earrings so that he can begin to understand what the size of the design should be. Anton then wonders out loud if he could design something else of the same size. Mike suggests that Anton could design a "finger thing". The teacher agrees, because this is about the same size. The teacher highlights that the idea of this maker challenge is to measure the design.

Example 3

1. Student 1/Anton: "What should I do now? I want to do a wristband and then to 3D print it". [It is on his computer. The teacher approaches him and stands beside him with a hand on her jaw.]
2. Teacher Beth: "But like [chuckles], the challenge is that at this first level, you must do some simple earring models".
3. Student 1/Anton: "Do I have to do the earring model?"
4. Teacher Beth: "Yes. At level one and they are done in 2D, which means that they are done as though you designed them on paper and cut them out and look at what they could be like. It has the idea that you perceive what the size is, so that when you start to draw bigger things or something else so that you know which is about the size [waves her hands in circles], like around which you move about. I mean in these instructions it is like you draw some earrings on paper, you cut them out and then you see if it is really a good size, can you move it a bit down-then [in reduced voice]. Wait here; you have to watch the video because I am not sure what it means".
5. Student 1/Anton: "I will wait until Mike [student 2] comes, I will do it with him, but is it obligatory to make an earring?"
6. Teacher Beth: "Um, well, like this is the order to get to the next level. So, you should, this, but you can, wait, it does not necessarily have to be. What else could it be apart from earrings?"
7. Student 2/Mike: "A finger thing!"
8. Teacher Beth: "Yes, for example [to Anton]. Did you hear this?"
9. Student 1/Anton: "Yes!"
10. Teacher Beth: "Because it is about the same size like the earring. So, the idea is that you measure it. Because after it you will do the digital modelling. The finger thing probably works as well as an earring".

The intervention episode demonstrated by Example 3 shows how Anton's personal interest to create a wristband and the requirements built into the maker challenge (to create earrings) did not match and thus created tension (lines 3 and 5). The episode demonstrates how the FUSE Studio makerspace, with its aim of promoting interest-driven learning, can turn into traditional classroom activity in which the student has to follow tasks and instructions with no opportunities for creative deviations from the plan (line 4). However, a productive resolution was reached in this episode, with the teacher and another student, Mike, coming up with a resolution: an alternative design idea that met the learning goals set for the task (lines 6, 8 and 9). Here, the teacher interprets the task not to be about designing an earring specifically (ie, about doing a school task) but more broadly about designing a small item (ie, about acquiring expertise on

measuring practices in the design process) (line 10). Unleashing as an intervention strategy enhanced the opportunity for creativity and followed the students' interests.

Discussion and conclusions

In this paper, we have investigated teacher interventions in students' collaborative work in an educational makerspace, the FUSE Studio situated in a Finnish school. This study not only continues the existing line of teacher intervention research in the field of computer-supported collaborative learning (see eg, Dawson, 2010; Greiffenhagen, 2012; Strømme & Furberg, 2015), but it also brings new knowledge about teacher interventions in a makerspace context—a context that has not yet received much research attention when it comes to understanding teacher interventions. Our study also creates added novelty to the study of teacher interventions in students' computer-supported collaborative work by its focus on both teacher- and student-initiated teacher interventions, as earlier research, by and large, has focused on teacher-initiated interventions.

The findings of our study show how a technology-rich makerspace context poses multidimensional demands and tensions for teacher interventions and teacher–student interactions, asking for a variety of skills and competencies from both the teachers and the students. In makerspaces, students' learning is not sequentially organised by a textbook or a pre-planned script, but they must navigate and integrate knowledge from several resources and domains. Such cognitive integration is known to be quite demanding (Bråten & Braasch, 2017; Ludvigsen, 2009). In our study, we depicted various interactional contexts and reasons for teacher interventions initiated both by the students and the teachers. The interactional contexts of teacher interventions dealt with the conceptual, procedural, technological, behavioural and motivational issues, evidencing the complexity and dynamicity of teaching and learning in a makerspace context. These findings also show that even though makerspaces hold potential for serving various students and their needs (Johnson & Halverson, 2015), there are nevertheless students who do not necessarily find maker activities motivating, and that students can demonstrate behaviour that requires teacher disciplinary actions.

The ratio of student-initiated (60% of all interventions) and teacher-initiated interventions (40%) revealed by our study, suggest that the students frequently sought help from the teachers, providing evidence of the traditional teacher and student positions maintained by the students themselves. These findings further confirm the finding that student and teacher initiations depended on the contents of the intervention. While conceptual- (76%), procedural- (90%) and technology-related interventions (75%) were mostly student initiated, most of behavioural (92%) and all of motivation-related (100%) interventions were teacher initiated. These findings further confirm the finding that the students were inclined to turn to their teachers whilst confronting challenges in their maker activities.

Moreover, in line with previous research (Strømme & Furberg, 2015), our study demonstrates the complexity and demands of teacher interventions in the context of the FUSE Studio makerspace. For instance, even though all the "hands on" materials needed for the maker challenges were within the students' reach, almost all of the procedurally related interventions were initiated by the students and the teachers orchestrated the selection and provision of the materials for the students. This finding connects with previous studies that have focused on the degree and nature of students' help seeking in classrooms (eg, Chiu, 2004; Ryan, Pintrich, & Midgley, 2001; Tan & Alant, 2018). This finding therefore contradicts the makerspace ideology that underscores students' ownership of their learning activity in makerspaces, for instance by being responsible for the materials and the workspaces (see also Penney, 2016).

Three leading teacher intervention strategies were identified that characterised the ways in which the teachers supported the students' in joint interactions, namely (1) authoritative, (2) orchestrating and (3) unleashing strategies. These were identified across the teacher–student interactions dealing with the conceptual, procedural, technological, behavioural and motivational issues. Authoritative strategies entailed the teacher taking responsibility for the work, and hence maintaining a dominant expert position in teacher–student interaction. The teachers' orchestrating strategies included inviting, balancing and gluing together the students' experiences and knowledge in problem-solving, with an effort to promote peer collaboration and relative expertise between the students and teachers. When unleashing, the teachers created an interactional space for the students to take the responsibility for the situation, encouraging the students to move beyond the actual maker challenges towards alternative creative processes.

Our findings provide a variety of examples of the situations in which the students' activity benefitted from teacher interventions in the FUSE Studio makerspace. When utilising the intervention strategies of orchestrating and unleashing, the teachers provided opportunities for the students' responsibility over their activity positioning students as actors and authors of their learning (Brown & Renshaw, 2006; Greeno, 2006; Kumpulainen & Lipponen, 2010). This was demonstrated in those situations in which the teachers invited the students to support their peers, enhancing the development of the students' relative expertise and collaborative problem solving, as well as diminishing their own role as the sole expert (see also Penney, 2016; Stevens *et al.*, 2016).

We could also identify the teachers' authoritative strategies in their interventions to the students' work. Typically, this occurred when the students did not know how to proceed (see also Ding *et al.*, 2007). Although some studies have pointed out the value of authoritative teacher strategies in supporting students when they are unfamiliar with the task (see eg, Ding *et al.*, 2007), in the makerspace context that underscores peer tutoring and relative expertise among teachers and students, teachers' authoritative strategies can also be viewed as problematic as they are known to reinforce the traditional teacher position in the classroom, where the teacher-expert transmits knowledge to the students, discourages dialogic interaction between teachers and students, and prevents students from taking responsibility for their work and learning (eg, Grasha, 1994; Kovalainen & Kumpulainen, 2005; Kumpulainen & Wray, 2002). Yet, supporting more interactive approaches and harnessing peer resources has been found to have positive effects on both successful problem-solving and students' thinking skills (Chiu, 2004; Ding *et al.*, 2007; Johnson & Johnson, 2002). Taken together, these findings point out how the strategies teachers use while intervening in students' work are multidimensional and tension-laden processes in which learner-centred pedagogies and the stabilised institutionalised structures of teacher-centredness challenged one another (see also Dougherty, 2012). Here, attention needs to be paid to teachers being able and willing to share the cognitive work and responsibilities with students.

Our study echoes earlier research indicating that the teachers' habitual responses to classroom situations, such as the need for control and order in classrooms, are difficult to change (Hofmann & Mercer, 2016; Rainio, 2008). To transform their customary teaching activity and to develop professionally, the facilitating teachers need new competencies to handle the pedagogical and technological infrastructure of makerspaces proficiently. Moreover, such novel learning environments call for the development of increasingly flexible ways of working with students and with teams of teachers. Managing the new demands and tensions associated with technology-rich makerspaces requires continuous efforts, both from the students and the teachers (Furberg, Kluge, & Ludvigsen, 2013; Kumpulainen *et al.*, 2018). Furthermore, moving from authoritative interaction to collaborative interaction requires collective efforts and cultural change. Altogether,

this study points to the importance of more research work on the role of the teacher in supporting students' learning in makerspaces. That is, how to navigate and balance the need for structure and support while maintaining students' agency and sustained interest in making and learning within institutional constraints. We also acknowledge the relatively low participation of girls (only half compared to boys) in our study, and call for further research on creating STEM education that is responsive to diverse students.

Statements on open data, ethics and conflict of interest

The research on which this study is based follows the ethical standards set forth by the Finnish National Board on Research Integrity. A formal record provided by the Data Protection Ombudsman in Finland was submitted to the City of Helsinki regarding personal data processing in the research project. Written permission to conduct the research was acquired from the City of Helsinki and its two schools, including the principal and teachers in which the research took place. The students' guardians were informed about the research and its data collection methods and were asked to give their written consent for their children's participation in the research. Participation in the research was voluntary and could be ended at any time. The research respects the teachers' and children's anonymity and privacy, and all names mentioned in the research are pseudonyms. Pictures and videos of the children and their teachers can only be used in the research if written consent has been obtained from the participants. The data collected for the research are stored carefully in a safe space. The research data cannot be shared outside the research group with any third parties.

We do not have ethics approval to make the raw data from this study available for sharing.

We have no conflicts of interest to declare.

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